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HEAT-DAMAGED WHEAT

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INTRODUCTION

Heat-damaged wheat is one of the most important types of damaged wheat found on the market. The damage is of a character that is difficult to deal with, and a small quantity of heat-damaged kernels in a lot of wheat brings down the price decisively. Conservative estimates place the annual loss caused by heat damage to wheat at close to $2,000,000.

In certain years, heat damage to wheat is especially prevalent, as in 1921 and 1922, when the total loss from this cause far exceeded this estimate. In the six-month period, July 1 to December 31, 1922, a total of 41,379 carloads of wheat were received at the Kansas City market, of which 1,841 cars or nearly 4½ per cent, graded one or more grades lower than would have been the case had they not contained heat-damaged kernels.

The difference in price per bushel between sound wheat and wheat containing heat-damaged kernels ranged from 5 to 15 cents or more in extreme cases. Assuming that the difference in price per bushel averaged 10 cents and that these cars contained 2,209,200 bushels of wheat, an average of 1,200 bushels per car, the losses sustained in the Kansas City market alone during that six-month period because of heat-damage totaled $220,920. Furthermore, as the prevalence of heat-damaged wheat in any market has a tendency to depress the price of all other wheat in that market, the total loss caused by damaged wheat may have been considerably higher than this figure.

[1] Credit is due to the personnel of the milling and baking laboratory of the Bureau of Agricultural Economics, J. H. Shollenberger, in charge, for the milling and baking data discussed in this bulletin.

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Other markets suffered losses in proportion to their volume of business, and the extent of the heat damage in the wheat handled by them.

That year the occurrence of heat-damaged wheat centered in the hard winter-wheat belt—Kansas, Oklahoma, and Texas—but to some extent it extended east into the soft wheat areas and north into the spring-wheat areas.

CAUSES OF HEAT DAMAGE TO WHEAT

The chief causes of heat damage to wheat are unfavorable weather conditions at the time of harvest and faulty methods of handling the crop during the period from harvest to the time the crop is marketed. The condition in which the wheat is stored on the farm or at the country elevator is an important factor. In recent years a great deal of damage to wheat has been caused by stacking green or wet wheat, or by threshing such wheat when it was too green or too wet, and storing it in bulk, without first putting it in suitable condition for storage. Under such conditions rapid intramolecular respiration takes place in the kernel, and heat developes. The action is accelerated as the temperature rises. According to the intensity of the heat developed, the wheat kernels become darkened in color, the gluten is weakened, or the wheat becomes unfit for human consumption.

Wheat that becomes discolored in this way in the bin is called bin-burned wheat. When the fermentation takes place in bundles or in header stacks, the term stack-stained, or header-damaged is usually applied.

PURPOSE OF THE INVESTIGATIONS

Studies made of crop conditions on the farm and at country and terminal elevators showed that individual lots of wheat contained from a fraction of 1 per cent to over 80 per cent of heat-damaged kernels. During the fermentation process the kernels change in color from light yellow or amber through the various shades of brown until, in extreme cases, they reach a deep mahogany color. Stack-stained and header-damaged wheat varies somewhat, but is usually dark green or deep brown in color.

Speculation has always prevailed as to the milling and baking quality of such damaged and discolored wheat. Discussion is especially keen as to how the various types and colors vary in milling and baking value.

Investigations were planned to determine the milling and baking value of heat-damaged kernels of various types and to study the influence that heat-damaged kernels of various types had on milling and baking tests, (1) when these kernels occurred naturally in marketed wheat, and (2) when these kernels were mixed with sound wheat.

SOURCES OF MATERIAL STUDIED

Material for this investigation was secured from three sources: (1) Grain of known origin that had been heat-damaged naturally was secured from farm granaries; (2) other heat-damaged wheat of unknown origin was secured from commercial lots of grain arriving at terminal markets; and (3) heat-damaged wheat was made by artificial means under controlled laboratory conditions.

Seven of the samples studied represented the hard red winter wheat class, two represented the hard red spring wheat class, two represented the durum wheat class, one represented the common white wheat class, and one represented the soft red winter wheat class.

METHODS OF ANALYSIS USED

All of the chemical and milling and baking tests recorded in this bulletin were carried out in accordance with the instructions given in Department Bulletin 1187.[2]

PHYSICAL, CHEMICAL, MILLING, AND BAKING PROPERTIES OF HEAT-DAMAGED WHEAT OF VARIOUS DEGREES OF DISCOLORATION

BIN-BURNED WHEAT

For a study of bin-burned wheat two samples of Kansas-grown hard red winter wheat were secured from farms in order to prevent the possible mixing or contamination of the wheat with wheat from other sources.

Sample 8085 was the first one studied. The wheat from which this sample was taken was harvested in damp weather with a combined harvester-thresher and was stored while damp in a 5,000-bushel steel bin. When examined several months afterward, the wheat had evidently gone through a very severe fermentation process, for analysis showed that 46 per cent of the kernels had been noticeably discolored by the heat developed during the fermentation process. The other 54 per cent were practically normal in color, as far as the eye could detect. The discolored kernels varied in shade from light brown to deep mahogany.

Speculation has always been rife as to the milling and baking qualities of the incipient light-brown kernels, often called skin-burned or twilight kernels, as compared with sound wheat or wheat of an even darker color. Sound, slightly damaged, and badly damaged kernels were separated by hand from the original sample in quantities large enough to make comprehensive physical, chemical, milling, and baking tests. Each original sample was given a number, and each separation from the original sample was designated as follows: Number 8085, the original sample; A, the sound wheat; B, the light-brown "skin-burned" wheat, sometimes called twilight kernels of wheat; and C, kernels of a decided mahogany color.

While the separations were being made, it became apparent that it would be almost impossible to secure a perfect separation of kernel types, the separations, therefore, were not 100 per cent true to the described type. After the separations were made the kernels of each type were examined to see whether kernels of other types were present, and these findings are given as footnotes in Table 1. In this table will be found in detail the results of the physical, chemical, milling, and baking tests made on the sound, slightly discolored, and badly discolored wheat kernels. All separations had a musty odor, which carried through into the flour and the baked loaf of bread.

Eliminating the factor of odor, the only outstanding physical factor modified by the fermentation process was that of texture of kernel.

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[2] SHOLLENBERGER, J. H., MARSHALL, W. K., and COLEMAN, D. A. EXPERIMENTAL MILLING AND BAKING (INCLUDING CHEMICAL DETERMINATIONS). U. S. Dept. Agr. Bul. 1187, 54 p., illus. 1924.

In the separations made from sample 8085 there was slightly less crude protein in the mahogany-colored wheat kernels than in the other kernels. The gliadin, water-soluble nitrogen, and crude fat were also present in lesser amounts as the kernels became darker in color. The total acidity, expressed as lactic acid, was less in the discolored kernels than in the sound kernels. This would indicate a decomposition of acid-reacting constituents as the fermentation process progressed.

The milling results on sample 8085 and its separates showed that the skin-burned sample 8085–B, yielded practically as much flour as the sound sample 8085–A. The mahogany kernel of sample 8085–C yielded 1.9 per cent less flour than 8085–A.

TABLE 1.—*Physical characteristics and chemical composition of heat-damaged wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat								Chemical composition of the wheat (basis, 13.5 per cent moisture)					Milling yields		
	Test weight per bushel	Moisture content	Sound kernels	Heat-damaged kernels	Kernels damaged otherwise than by heat	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water-soluble nitrogen	Crude fat	Acidity as lactic acid	Flour	Bran	Shorts
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8085 [2]	57.2	11.0	54.0	43.0	3.0	0	45.8	S. G. H. W.[3]	10.92	6.49	0.298	1.46	0.301	72.6	13.2	12.8
8085–A [4]	57.3	11.7	96.1	3.9	0	0	25.0	No. 5 H. W.[5]	10.89	6.54	.354	1.50	.353	72.0	13.8	13.1
8085–B [6]	56.7	11.6	1.2	98.8	0	0	18.3	S. G. Y. H. W.[7]	10.70	6.49	.335	1.44	.241	72.2	13.9	12.8
8085–C [8]	57.5	11.5	0	100.0	0	0	2.5	——do.[7]	10.36	5.20	.255	1.43	.233	70.6	12.5	16.2

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [1]	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
8085 [2]	9.58	18.30	7.82	7.20	0.603	0.210	67.7	1,495	507	45.0	Brown	33.0	44	Musty.
8085–A [4]	9.61	26.60	10.11	7.67	.484	.187	68.5	2,065	699	83.5	Cream	86.2	52	Do.
8085–B [6]	8.30	None.	None.	7.65	.571	.220	66.7	1,445	489	37.5	Brown	52.0	45	Do.
8085–C [8]	8.05	None.	None.	5.78	.690	.247	69.7	1,020	341	10.0	Dark brown	13.0	52	Do.

[1] Water absorbed plus water originally present in the flour.
[2] 8085 is the original sample and contains 54 per cent of 8085–A, 19.3 per cent of 8085–B, and 23.7 per cent of 8085–C.
[3] Sample grade hard winter.
[4] 8085–A is the sound wheat separated from 8085. It contains 3.9 per cent of 8085–B.
[5] Hard winter.
[6] 8085–B is the light brown, skin-burned kernels, sometimes called twilight kernels. It contains 1.2 per cent of 8085–A and 5.5 per cent of 8085–C.
[7] Sample grade yellow hard winter.
[8] 8085–C consists of kernels of a pronounced mahogany color.

Chemical analysis showed that the flour milled from the badly discolored wheats did not contain as much crude protein as did the flour milled from the sound wheat. This was due, no doubt, to the double effort to keep the bran out of the flour and to obtain a flour with a low ash content, as the bran from the discolored samples, 8085–B and 8085–C, chipped rather than flaked off.

The quality of the protein was decidedly injured in the discolored kernels, as it was absolutely impossible to obtain any washed gluten from the flour milled from samples 8085–B and 8085–C. The gliadin in the flour milled from sample 8085–C was less in amount than that in 8085–A.

The ash content of the flour milled from samples 8085–B and 8085–C is indication of milling difficulties. The greater ash content was associated with kernels showing the greatest amount of discoloration.

The titratable acidity of the flour, expressed as lactic acid, increased in quantity as the color of the kernel deepened. It should be pointed out that this is the opposite of the acidity values found in the wheat samples before milling.

FIG. 1.—Loaves of bread baked from bin-burned wheat. From left to right, loaves baked from flour milled from samples 8085, 8085–A, 8085–B, and 8085–C

The chemical data regarding the composition of the wheats and the flour milled from them are reflected in the baking results.

Compared with the bread made from the sample of sound wheat, 8085–A, the bread made from the skin-burned sample, 8085–B, suffered a reduction of 30 per cent in loaf volume because of the fermentation process, whereas the mahogany kernels, sample 8085–C, suffered a reduction in loaf volume of approximately 50 per cent. The texture of the crumb, the shade of the crumb, and the color of the crumb in the bread made from samples 8085–B and 8085–C were progressively inferior to those found in the sound sample 8085–A. A picture of the loaves of this bread is shown as Figure 1.

A companion sample, 10016, was studied in the same way as was sample 8085. This lot of wheat was also grown in Kansas. It was harvested while damp and stored in a wooden bin. On receipt at the grain research laboratory it contained 40.5 per cent discolored kernels.

In this study, sample 10016 represented the original sample from which the discolored kernels were separated by hand. Sample 10017 represented the sound wheat separated from 10016. Sample 10018 represented the light tan, skin-burned kernels, and sample 10019 represented the mahogany kernels.

The purity of each separation is noted in Table 2. In this table will also be found the results relating to the physical, chemical, milling, and baking properties of the wheat in each separation.

The original sample, as well as each separation, had a musty odor, and this odor carried through into the flour and into the baked loaf of bread.

TABLE 2.—*Physical characteristics and chemical composition of naturally heat-damaged wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat								Chemical composition of the wheat (basis, 13.5 per cent moisture)					Milling yields		
	Test weight per bushel	Moisture content	Sound kernels	Heat-damaged kernels	Kernels damaged otherwise than by heat	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water soluble nitrogen	Crude fat	Acidity as lactic acid	Flour	Bran	Shorts
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10016 [2]	56.2	10.5	59.5	38.5	2	0	7.8	S. G. H. W.[3]	10.74	6.07	0.273	1.63	0.435	71.3	14.72	11.89
10017 [4]	56.9	11.3	96.0	2.0	2	0	6.5	No. 5 H. W.[5]	10.70	6.49	.301	1.77	.377	71.4	17.19	9.95
10018 [6]	56.0	11.5	0	98.0	2	0	5.0	S. G. H. W.[3]	10.40	5.68	.246	1.62	.270	71.2	12.94	13.49
10019 [8]	56.7	11.4	0	98.0	2	0	3.5	do	10.87	3.54	.207	1.60	.233	70.9	13.62	14.59

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [1]	Volume of the loaf	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
10016 [3]	9.59	15.94	7.09	6.83	0.637	0.241	68.0	1,265	434	28	Light	41	32	Musty.
10017 [4]	9.39	22.71	9.28	7.92	.513	.215	69.4	1,700	578	77	Dark / Cream	66	47	Do.
10018 [6]	9.22	(7)	-------	5.94	.593	.291	68.5	1,060	537	14	Brown	30	30	Do.
10019 [8]	9.52	(7)	-------	4.01	.790	.386	84.6	915	385	5	Dark brown	6	21	Do.

[1] Water absorbed plus water originally present in the flour.
[2] 10016 is the original sample and contains 59.5 per cent of 10017, 16 per cent of 10018, and 22.5 per cent of 10019.
[3] Sample grade hard winter.
[4] 10017 is the sound wheat separated from 10016. It contains 2 per cent of 10018.
[5] Hard winter.
[6] 10018 is the light brown, skin-burned kernels, sometimes called twilight kernels. This sample contains 6.1 per cent of 10019.
[7] Not recoverable.
[8] 10019 consists of kernels of a pronounced mahogany color. This sample contains 2 per cent of 10018.

The fermentation process did not affect the test weight per bushel to any appreciable extent. As was found in the case of sample 8085, the only noticeable modification in the physical composition of the wheat was a decrease in the percentage of dark, hard, and vitreous kernels as the color of the kernel increased.

The crude protein content of the various separates did not follow any definite law. The percentage of gliadin, water-soluble nitrogen,

and crude fat decreased as the kernels changed from normal color to deep mahogany. This was the same condition found in the case of sample 8085.

The titratable acidity, expressed as lactic acid, was less in the discolored kernels of the two types than in the sound kernels.

The milling data relating to sample 10016 and its separates showed that the skin-burned kernels, sample 10018, yielded practically as much flour as the sound sample, 10017. The mahogany kernels, sample 10019 yielded slightly less flour than either 10017 or 10018. Although the yields were equivalent, there was a decrease in flour quality, as the ash content of the flours milled from samples 10018 and 10019, was much greater than the ash content of sample 10017. But the ash in sample 10018 was approximately 16 per cent higher than that in 10017, and the ash in 10019 was approximately 33 per cent higher than that in sample 10018.

Observations made at the time of milling indicated that the bran coats of the discolored kernels, samples 10018 and 10019, were more brittle than those of the sound sample, 10017, and had a tendency to chip off from the wheat kernel, rather than to flake off, as is usually

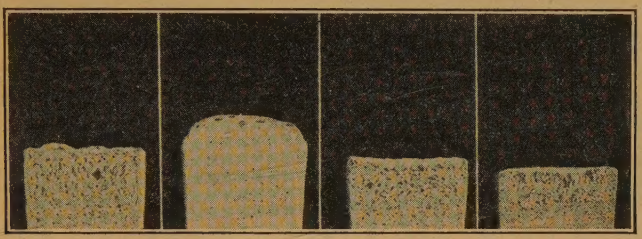

FIG. 2.—Loaves of bread baked from bin-burned wheat. From left to right, loaves baked from flour milled from samples 10016, 10017, 10018, and 10019

the case. The result was that it found its way into the flour and raised the ash content of the flour in the way shown.

Examination of the flour showed the gluten quality to be decidedly injured in the discolored samples, as it was impossible to wash any gluten from the flour milled from samples 10018 and 10019.

The percentage of gliadin diminished progressively with the degree of kernel discoloration.

The titratable acidity of the flour, expressed as lactic acid, increased as the color of the kernel increased. It will be remembered that the reverse of this was true regarding the wheat samples before milling.

The chemical data regarding the composition of the wheats and the flour milled from them are reflected in the baking results.

Compared with the bread made from sample 10017, the bread made from sample 10018 had 37.6 per cent less loaf volume, whereas the bread made from the flour milled from sample 10019 had 46 per cent less loaf volume. The texture of the crumb, the shade of the crumb, and the color of the crumb in the bread made from samples 10018 and 10019 were progressively inferior to those found in the sound sample 10017. A picture of the loaves of this bread is shown as Figure 2.

With these samples also there was a decided parallelism between the fermentation time and the discoloration of the kernels. The fermentation time was shorter with the flours milled from the darkest colored kernels.

As further material for study, a sample of heat-damaged wheat was obtained at a terminal market. This sample of wheat was from the hard red winter class. Upon receipt at the terminal market the sample contained 42.5 per cent of distinctly discolored wheat kernels, 20.9 per cent of which were heat damaged. Some of the kernels in this sample were of a slightly different type from those previously described under the tests made upon samples 8085 and 10016.

For this reason the original sample and four separations were tested. They were numbered as follows: 8263, the original sample before separation of the various types of kernels; 9250, bleached and weathered kernels which were evidently mixed into the original sample; 9251, kernels of a light-yellow color, apparently sound; 9252, kernels of light-tan to incipient-mahogany color; 9253, kernels of decided mahogany color.

The purity of type of kernel and the results of the physical, chemical, milling, and baking tests made on these separations are given in Table 3.

TABLE 3.—*Physical characteristics and chemical composition of naturally heat-damaged wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat								Chemical composition of the wheat (basis, 13.5 per cent moisture)				Milling data
	Test weight per bushel	Moisture content	Sound kernels	Heat-damaged kernels	Kernels damaged otherwise than by heat	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Water-soluble nitrogen	Crude fat	Ash	Flour yields
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8263 [2]	59.0	12.2	57.5	20.9	21.6	0	6.5	S. G.[3]	11.20	0.262	1.82	1.84	69.1
9250 [4]	56.8	9.9	80.0	0	20.0	0	36.5	do.[3]	11.82	.366	1.88	2.04	71.7
9251 [5]	60.4	10.2	94.0	6.0	0	0	21.9	do.[3]	9.43	.222	1.95	1.70	73.9
9252 [6]	59.6	10.0	0	100.0	0	0	0	do.[3]	10.17	.217	1.79	1.81	74.0
9253 [7]	56.4	10.0	0	100.0	0	0	27.5	do.[3]	11.18	.242	1.65	1.78	71.4

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data								
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [1]	Volume of the loaf	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
8263 [2]	10.40	25.91	11.61	6.37	0.610	0.576	69.1	1,450	483	40	Brown	30	53	Musty.
9250 [4]	11.72	31.54	11.60	9.70	.654	.545	73.0	2,270	771	89	Gray	65	56	Do.
9251 [5]	8.69	11.53	5.05	6.94	.672	.601	73.2	1,330	447	30	Light brown.	55	38	Very musty.
9252 [6]	9.45	None.	None.	6.91	.789	.583	80.0	1,050	352	8	Brown	30	17	Do.
9253 [7]	10.33	None.	None.	6.34	.841	.577	81.6	950	317	5	Dark brown	5	26	Do.

[1] Water absorbed plus the water present originally in the flour.
[2] 8263 is a commercial sample of hard red winter wheat containing 20.9 per cent of heat-damaged kernels.
[3] Sample grade.
[4] 9250 contains bleached kernels. This wheat had evidently been mixed into the sample. The sample contains 5.6 per cent of 9252 and 0.7 per cent of 9253.
[5] 9251 contains kernels of a light yellow color and are apparently sound. In this sample is 4.7 per cent of 9252.
[6] 9252 contains kernels of a light tan color. Some kernels were beginning to become mahogany color.
[7] 9253 contains kernels of a decided mahogany color.

After a study of the chemical data presented, particularly that on the crude protein content of the wheat, it seems probable that this sample represents an elevator mixture rather than a virgin sample. For this reason, it may be questioned whether samples 9252 and 9253 can be fairly compared as later developments of sample 9251. Nevertheless the results obtained with the two types of discolored kernels were almost in accord with those previously cited from the results of the investigations made on samples 8085 and 10016. The other outstanding exception, in addition to the crude-protein tests cited above, was the decrease in test weight per bushel as the discoloration of the wheat kernel increased.

The water-soluble nitrogen and the crude fat of the wheat diminished in quantity as the kernels became more mahogany colored with the exception of the water-soluble nitrogen in sample 9253.

The quality of the gluten even in the apparently sound kernel was seriously injured, and the gluten in the discolored samples, 9252 and 9253, was injured so badly that it could not be washed from the flour.

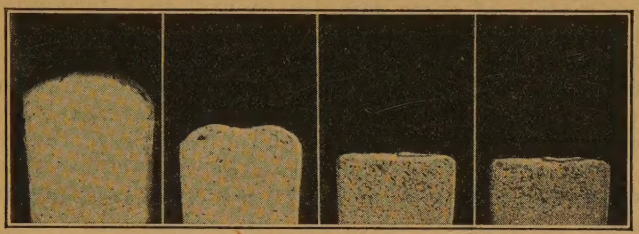

FIG. 3.—Loaves of bread baked from separations made on sample 8263. From left to right, loaves baked from flour milled from samples 9250, 9251, 9252, and 9253.

The milling quality of each sample of the discolored wheat was poor. The bran coats chipped rather than flaked off, and as a result the flour milled from each of the two types of discolored kernels had a high ash content. In addition, a lowered flour yield was obtained from sample 9253.

Tests for flour acidity expressed in terms of $_{P}H$ rather than in lactic acid showed that the active acidity of each of the flours milled from the discolored kernels of the two types had a larger active acidity than the flour milled from the sound wheat samples.

The volume of the loaf of bread, the texture of the crumb, the shade of crumb, the color of crumb, and the odor of the hot loaf were all increasingly inferior as the wheat kernels became darker in color. A picture of these loaves of bread is shown as Figure 3.

The chemical, milling, and baking data obtained as a result of the tests made on the bleached and weathered kernels, sample 9250, were not greatly different, outside of the factors of odor and color of crumb, from those of the average milling and baking quality of hard red winter wheat as reported by Shollenberger et al.[3]

[3] SHOLLENBERGER, J. H., COLEMAN, D. A., and PHILLIPS, C. L. PROTEIN AND GLUTEN IN WHEAT AND FLOUR. U. S. Dept. Agr., Bur. Agr. Econ. Abs. and Ref., no. 12, p. 36. 1923. [Mimeographed.]

ARTIFICIALLY HEAT-DAMAGED WHEAT

The baking results obtained from the sound portions of samples 8263 and 10016 suggested that even though the wheat kernel might appear normal and sound as far as the eye could detect, its milling and baking properties might be seriously affected. To obtain information on this point experiments were planned in which a series of hard winter wheat samples were artificially heat-damaged in the laboratory in the following way: To four 2,000-gram portions of the same lot of hard red winter wheat, water was added, so that four differing lots resulted, containing 13.85, 15.13, 17.01, and 18.54 per cent of moisture. When the moisture in the samples had become uniform throughout, the moistened wheat samples, and a check sample to which no moisture had been added, were placed in separate jars and sealed. The jars and contents were then held in an incubator at a temperature of 98 to 100° F. for 90 days. At the end of that time the jars were removed, the wheat was allowed to dry out, and the physical, chemical, milling, and baking tests reported in Table 4 were made upon all five samples.

An examination of these samples showed that fermentation had taken place to the extent that 0.5 per cent of the kernels in sample 8651, 25.3 per cent of the kernels in sample 8652, and 47.6 per cent of the kernels in sample 8653 were distinctly heat-damaged. Accompanying the appearance of the discolored kernels there was a reduction in test weight per bushel and a decrease in the percentage of dark, hard, and vitreous kernels. The commercial grade of the sample was reduced from a No. 2 hard winter to sample grade yellow hard winter.

TABLE 4.—*Physical characteristics and chemical composition of artificially heat-damaged hard winter wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat								Chemical composition of the wheat (basis, 13.5 per cent moisture)					Milling data, flour yields
	Test weight per bushel	Moisture content	Sound kernels	Heat-damaged kernels	Kernels damaged otherwise than by heat	Foreign material	Dark hard and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water-soluble nitrogen	Crude fat	Acidity as lactic acid	
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8649 [1]	59.0	11.2	99.8	0	0.1	0.1	33.6	No. 2 H. W.[2]	10.57	6.10	0.296	1.72	0.230	69.5
8650 [3]	56.8	12.7	99.7	0	.3	Trace.	28.0	No. 3 H. W.[2]	10.73	6.10	.266	1.70	.297	69.7
8651 [4]	56.4	12.0	98.4	.5	.9	.2	17.0	No. 3 Y. H. W.[5]	10.77	6.21	.281	1.67	.295	69.9
8652 [6]	55.6	12.8	73.8	25.3	.7	.2	10.2	S. G. Y. H. W.[7]	10.72	6.10	.248	1.62	.296	69.4
8653 [8]	55.1	12.4	51.9	47.6	0	.5	3.3	-----do.[7]	10.63	6.21	.241	1.63	.296	70.5

[1] 8649 may be regarded as the check sample as it was not treated. It contained 11.2 per cent of moisture. Samples 8650, 8651, 8652, 8653 were moistened with water in varying amounts as indicated below and incubated in sealed jars 90 days at a temperature of 98° to 100° F.

[2] Hard winter.

[3] 8650 contains 13.85 per cent moisture.

[4] 8651 contains 15.13 per cent of moisture.

[5] Yellow hard winter.

[6] 8652 contains 17.01 per cent of moisture.

[7] Sample grade yellow hard winter.

[8] 8653 contains 18.54 per cent of moisture.

TABLE 4.—*Physical characteristics and chemical composition of artificially heat-damaged hard winter wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*—Continued

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [9]	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C.c.*	*Score*		*Score*	*Minutes*	
8649 [1]	9.25	21.53	8.90	7.47	0.375	0.137	68.8	2,230	768	92.5	Cream	89.0	86	Natural.
8650 [3]	9.10	21.13	9.08	7.47	.488	.154	68.2	2,040	699	88.0	Dark cream	88.0	84	Slightly musty.
8651 [4]	9.03	11.87	5.38	7.41	.545	.173	65.8	1,440	489	72.5	Light brown	72.5	66	Musty.
8652 [6]	9.37	2.35	1.16	7.30	.611	.216	65.6	1,130	383	10.0	Brown	40.0	50	Putrid.
8653 [8]	9.36	None.	None.	7.35	.660	.248	63.7	980	333	5.0	Dark brown	20.0	46	Do.

[1] 8649 may be regarded as the check sample as it was not treated. It contained 11.2 per cent of moisture. Samples 8650, 8651, 8652, 8653 were moistened with water in varying amounts as indicated below and incubated in sealed jars 90 days at a temperature of 98° to 100° F.

[3] 8650 contains 13.85 per cent moisture.

[4] 8651 contains 15.13 per cent of moisture.

[6] 8652 contains 17.01 per cent of moisture.

[8] 8653 contains 18.54 per cent of moisture.

[9] Water absorbed plus water originally in the flour.

As was the case with the naturally heat-damaged wheats, the water-soluble nitrogen and the percentage of crude fat were reduced as the percentage of heat-damaged kernels increased.

The quality of the gluten in the flour milled from these wheats showed decided deterioration when only 0.5 per cent of the kernels showed evidence of having been damaged. With this percentage of heat damaged kernels in the sample, it was only possible to obtain a little more than 50 per cent of the gluten, and when the percentage of heat-damage was larger, as in samples 8652 and 8653, little or no gluten was obtained.

The ash in the flours milled from wheats containing heat-damaged kernels increased as the percentage of heat-damaged kernels became larger. The ash of the flour milled from sample 8653 was almost double the amount found in the flour milled from the check sample.

The acidity of the flours, expressed as lactic acid, increased in intensity along with the ash content. The volume of the loaf of bread, the texture of the crumb, the shade of the crumb, the color of the crumb, and the odor of the loaf of bread became increasingly inferior as the percentage of heat-damaged kernels became greater. A picture of the loaves of bread baked from these flours is shown in Figure 4.

Indicative of a weakened condition is the shorter proofing period for the flours milled from the heat-damaged wheats.

To answer the question which prompted the investigation, whether wheat may appear sound but still be seriously injured, a comparison is made of the results obtained from sample 8649, which was free from heat-damaged kernels, with the results obtained from sample 8651, which contained only 0.5 per cent of heat-damaged kernels.

Even with this small quantity of heat-damaged kernels, this sample suffered a reduction in gluten quality of about 40 per cent, and a marked reduction in all bread-making factors. Evidently the occurrence of even a smaller quantity of heat-damaged kernels than 0.5 per cent in country-run wheat that has not been through an elevator and mixed is a warning that such wheat is a decided milling risk.

This fact is further brought out by some experiments made in the way described above on some durum wheats which were not discolored

FIG. 4.—Loaves of bread baked from artificially created heat-damaged hard red winter wheat. From left to right, loaves baked from flour milled from samples 8649, 8650, 8651, 8652, and 8653

and did not appear to be seriously damaged in any way as a result of the same conditions to which samples 8649 to 8653 were exposed. The data given in Table 5 show that none of the kernels in any of the treated samples had any appearance of being damaged by heat of fermentation, yet all the factors associated with the heat-damaged phenomena, as found in the previous studies, were present, so that the presence of very small quantities of heat-damaged kernels in other

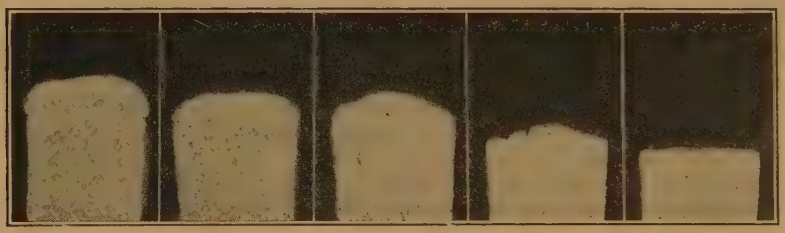

FIG. 5.—Loaves of bread baked from flour milled from artificially created heat-damaged durum wheat. From left to right, loaves baked from samples 8654, 8655, 8656, 8657, and 8658

classes of wheat is significantly important. Figure 5 shows the character of the baked loaves.

STACK-STAINED AND HEADER-DAMAGED WHEAT

The header is still used to a large extent for harvesting wheat in the hard red winter wheat area. This machine cuts the growing wheat just a few inches below the heads and then elevates the heads into a wagon barge. Header wheat is usually stacked and left to cure before it is threshed. There is danger of this headed wheat heating in the stack before it is threshed if the harvesting is done before the grain is ripe or when the grain is too wet. Heating in the stack is also likely to take place if there is a large quantity of moist green weeds among the wheat heads. Such damage in the wheat harvested

by the header is commonly known as header damage or stack stain. In recent years threshing has been done direct from the header by means of a small thresher hauled beside it, or by means of a "combine," which is a header and thresher combined. Grain threshed direct from the header or by a combine may likewise become a storage risk if harvested when too green or too moist.

TABLE 5.—*Physical characteristics and chemical composition of artificially heat-damaged Durum wheat, effect of heat damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat								Chemical composition of the wheat (basis, 13.5 per cent moisture)					Milling data
	Test weight per bushel	Moisture content	Sound kernels	Heat damaged	Kernels damaged otherwise than by heat	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water soluble nitrogen	Crude fat	Acidity as lactic acid	Flour yields
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
8654 [1]	60.0	11.4	99.2	0	0.8	0	80.3	No. 1 amber	13.59	8.32	0.310	2.08	0.315	69.3
8655 [2]	57.3	12.5	97.2	0	2.8	0	78.6	No. 3 amber	13.40	8.38	.274	2.17	.326	67.4
8656 [3]	57.1	13.0	96.6	0	3.4	0	78.2	do	13.40	8.21	.265	2.05	.325	66.7
8657 [4]	56.4	13.2	97.2	0	2.7	0	66.6	No. 3 Durum	13.14	8.44	.265	2.00	.305	62.9
8658 [5]	55.8	13.4	96.9	0	3.0	0	51.0	No. 4 Durum	13.44	8.38	.257	1.93	.325	62.9

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [6]	Volume of the loaf	Volume per 100 grams dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor and taste of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Min.*	
8654 [1]	12.88	36.69	13.09	9.58	0.623	0.233	76.0	2,320	682	90.0	Creamy	94.0	74	Natural.
8655 [2]	12.85	34.51	13.00	9.52	.686	.248	75.3	1,980	582	87.3	Dark creamy	73.5	74	Sour.
8656 [3]	12.77	29.89	12.06	9.46	.732	.269	74.2	1,840	541	88.0	Light brown	65.0	68	Slightly putrid.
8657 [4]	12.77	23.73	9.59	9.35	.754	.290	70.5	1,280	376	71.0	Brown	36.0	84	Putrid.
8658 [5]	12.70	4.99	2.23	9.01	.878	.315	75.5	1,010	297	10.0	Dark brown	15.0	83	Do.

[1] 8654 may be regarded as the check sample as it was not treated. It contains 11.4 per cent of moisture. Samples 8655, 8656, 8657, and 8658 were moistened with water in varying amounts as indicated below and incubated in sealed jars for 90 days at a temperature of 98° to 100° F.
[2] 8655 contains 13.58 per cent of moisture.
[3] 8656 contains 15.13 per cent of moisture.
[4] 8657 contains 17.01 per cent of moisture.
[5] 8658 contains 17.58 per cent of moisture.
[6] Water absorbed plus water originally present in the flour.

As the use of combines is increasing yearly, more stack-stained or header-damaged grain may be expected to be found on the market. Header-damaged kernels are discolored much as is grain threshed from the shock, but seldom to such great extent.

To study the effect of header damage on the quality of the wheat, and on the quality of the flour milled from header-damaged wheat,

separations from five lots were made. Four lots were wheat of the hard red winter class, and one was wheat of the hard red spring class.

STACK-STAINED HARD RED WINTER WHEAT

As in the case of the studies of bin-burned wheats, each of these header-damaged wheats was separated into three portions, according to the degree of discoloration of the kernel in the original samples, in sufficient amounts to make, in duplicate, a complete physical, chemical, milling, and baking study of each type of discoloration.

Sample 9204 was the first sample studied. It was a sample of Kansas-grown hard red winter wheat and contained approximately 10.8 per cent of stained kernels. The stain was particularly noticeable along the back of the kernels and was of a green to greenish-yellow shade.

Sample 9205 represented the residue after the removal of samples 9206 and 9207. Sample 9206 represented the dark, hard, and vitreous kernels in the sample that were entirely free from stain and apparently sound. Sample 9207 represented the vitreous kernels with a green or greenish-yellow cast, especially on the back of the kernel. Purity of type was as difficult to obtain in this study as in the previous studies; therefore, the relative purity of each type is given in Table 6 with the results of the physical, chemical, milling, and baking tests made on this series of samples.

The two separations of greatest interest were samples 9206 and 9207. Sample 9207 was, to all appearances, the same as sample 9206, with the exception that the kernels in 9207 had all been stained light green to yellowish-green.

A comparison of the results obtained from a study of sample 9206 and sample 9207 shows that the stack-stained sample, 9207, weighed less per bushel than sample 9206.

TABLE 6.—*Physical characteristics and chemical composition of header-damaged hard red winter wheat, effect of header damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat							Chemical composition of the wheat (basis, 13.5 per cent moisture)						Milling data (flour yields)
	Test weight per bushel	Moisture content	Heat-damaged kernels	Kernels damaged by stain	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water-soluble nitrogen	Crude fat	Acidity as lactic acid	Ash	
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
9204 [1]	57.3	10.2	0	10.8	0.7	87.4	No. 3 D. H. W. [2]	15.65	9.39	0.442	1.51	0.313	2.06	70.96
9205 [3]	57.0	9.9	0	2.5	.2	87.1	do. [2]	15.54	9.30	.397	1.61	.314	2.06	71.06
9206 [4]	58.4	9.7	0	3.8	Trace.	95.8	No. 2 D. H. W. [2]	15.07	9.23	.440	1.55	.316	2.03	70.91
9207 [5]	57.6	10.1	0	98.7	.1	98.0	No. 3 D. H. W. [2]	[6] 16.16	9.81	.496	1.51	.298	2.09	69.83

[1] 9204 is the original sample and contains 59.5 per cent of 9205, 13.7 per cent of 9206, and 10.8 per cent of 9207.
[2] Dark hard winter.
[3] 9205 is the residue after the removal of 9206 and 9207. It contains 5.6 per cent of 9206 and 2.5 per cent of 9207.
[4] 9206 is hard, vitreous kernels in the sample which are apparently sound.
[5] 9207 is vitreous kernels with a green or greenish-yellow cast, especially on the back of the kernel. This sample contains 1.3 per cent of 9206.
[6] Weedy odor on tempering.

TABLE 6.—*Physical characteristics and chemical composition of header-damaged hard red winter wheat, effect of header damage upon yield and composition of flour, and character of resulting loaf of bread*—Continued

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Water absorption of the flour [5]	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor and taste of the hot loaf
		Wet	Dry											
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
9204 [1]	14.83	50.10	16.38	12.62	0.588	0.170	77.4	1,990	668	87.0	Cream	86.2		Natural.
9205 [3]	14.77	48.80	16.03	13.01	.606	.178	77.2	1,937	650	87.5	do	86.5		Do.
9206 [4]	14.21	47.53	15.12	12.45	.587	.178	78.8	2,012	680	87.0	do	89.3		Do.
9207 [5]	15.08	50.01	16.19	13.16	.647	.178	77.7	1,992	667	86.7	do	86.9		[9].

[1] 9204 is the original sample and contains 59.5 per cent of 9205, 13.7 per cent of 9206, and 10.8 per cent of 9207.
[3] 9205 is the residue after the removal of 9206 and 9207. It contains 5.6 per cent of 9206 and 2.5 per cent of 9207.
[4] 9206 is hard, vitreous kernals in the sample which are apparently sound.
[5] 9207 is vitreous kernels with green or greenish-yellow cast, especially on the back of the kernel. This sample contains 1.3 per cent of 9206.
[5] Water absorbed plus water originally in the flour.
[9] Disagreeable, strawlike odor. Bitter taste.

The discolored sample, 9207, contained more crude protein and more water-soluble nitrogen and ash than the sound sample, 9206.

Less flour was obtained from sample 9207 than was obtained from sample 9206.

A chemical analysis of the flour showed that the flour milled from sample 9207 contained more crude protein, crude gluten, gliadin, and ash than did that from sample 9206.

Although the crude protein in the flour milled from sample 9207 was greater in amount than that in sample 9206, the water absorption of the flour was less.

The flour milled from sample 9207 yielded a loaf of bread with a disagreeable, strawlike odor. The bread was bitter to the taste, and in all points of comparison was of poorer quality than the loaf of bread made from the flour milled from sample 9206, which was not discolored in any way.

The second sample of header-damaged wheat studied was likewise of hard red winter wheat. This sample, No. 9739, was obtained from a farm in Oklahoma. It contained more pronounced types of stack-stained kernels than did sample 9204. In addition, it contained enough of the mahogany colored bin-burned kernels to make possible a further study of this type of kernel. Sample 9741 represented slightly stack-stained kernels of a light olive-green color. Sample 9742 represented the badly stack-stained kernels. These kernels were dark green in color, the shade of green popularly known as bottle green. Some of these kernels had a brown cast. Sample 9743 represented kernels of the mahogany type usually associated with bin-burned wheat. Sample 9740 represented the residue after the slightly stained light-green stack-stained kernels and the badly stained dark-green kernels had been removed.

The results of the tests made on sample 9739 and its separates are given in Table 7. It will be found, in that section of the table which relates to kernels of the stack-stained types, that practically the same results were obtained from a study of the physical, chemical, milling, and baking properties of stack-stained kernels of the two types as were obtained from a study of the stained sample, 9207. The results obtained from the study made with the mahogany kernels of the bin-burned type, represented by sample 9743, were of the same order as those found in the earlier studies of bin-burned wheat.

TABLE 7.—*The physical characteristics and chemical composition of header-damaged hard winter wheat, effect of header damage upon yield and composition of flour, and character of resulting loaf*

Laboratory No.	Physical characteristics of the wheat					Chemical composition of the wheat (basis, 13.5 per cent moisture)						Milling yields		
	Test weight per bushel	Moisture content	Damaged kernels (stained)	Dark, hard, and vitreous kernels	Commercial grade [1]	Crude protein	Gliadin	Water-soluble nitrogen	Ash	Crude fat	Acidity as lactic acid	Flour [2]	Bran	Shorts
	Lbs.	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
9739 [5]	57.5	10.9	2.8	45.0	No. 3 H. W. [6]	14.66	9.59	0.552	1.96	1.68	0.327	70.6	11.11	17.05
9740 [7]	58.0	10.2	.0	10.0	No. 2 Y. H. W. [8]	13.59	9.61	.479	1.99	1.77	.322	73.0	11.93	13.90
9741 [9]	58.1	10.1	100.0	50.0	No. 2 H. W. [6]	14.96	10.42	.539	1.95	1.76	.322	71.1	11.37	15.82
9742 [10]	57.7	10.1	100.0	100.0	No. 3 D. H. W. [11]	15.94	11.24	.557	2.01	1.79	.322	67.8	12.03	17.16
9743 [12]	56.0	9.7	[13]100.0	10.0	S. G. Y. H. W. [14]	------	------	------	------	------	------	60.7	12.79	------

Laboratory No.	Chemical composition of the flour (basis, 13.5 per cent moisture)						Baking data							
	Crude protein	Gliadin	Crude gluten		Ash	Acidity as lactic acid	Water absorption of the flour [3]	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor of the hot loaf [4]
			Wet	Dry										
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
9739 [5]	13.22	10.68	37.82	13.60	0.570	0.134	73.2	2,230	761	88.5	Cream gray	88.2	48	Earthy.
9740 [7]	12.58	10.49	35.62	12.28	.498	.126	74.2	2,205	747	88.8	do	90.3	58	Do.
9741 [9]	13.96	11.36	41.49	15.21	.545	.119	75.0	2,145	723	88.8	Dark cream gray.	89.5	56	Do.
9742 [10]	15.05	11.86	39.73	15.04	.667	.132	75.1	2,090	702	83.1	Dark gray	83.6	54	Do.
9743 [12]	10.73	8.47	27.11	10.38	.771	.158	69.2	1,550	519	86.0	Brown gray	15.0	40	Musty and strong.

[1] All the samples had a distinctly earthy and musty odor, increasing in intensity from 9740 to 9743, inclusive. The samples were graded as if no odor or stack stain were present.
[2] Distinct odor in flour.
[3] Water absorbed plus water originally present in the flour.
[4] Odor present in the hot loaf.
[5] 9739 is a sample of header-damaged hard red winter wheat.
[6] Hard winter.
[7] 9740 is the residue after kernels represented by 9741, 9742, and 9743 had been removed.
[8] Yellow hard winter.
[9] 9741 is slightly stack-stained kernels.
[10] 9742 is the pronouncedly stack-stained kernels.
[11] Dark hard winter.
[12] 9743 is bin-burned kernels.
[13] All the kernels were of a distinctly mahogany type.
[14] Sample grade yellow hard winter.

The most badly stained kernels, sample 9742, were somewhat lower in test weight per bushel than the more lightly stained kernels represented by sample 9741. The crude protein content, the percentage of water-soluble nitrogen, and the percentage of gliadin were higher in the stained samples than in the unstained portion of the original sample.

The flour yield of each of the stained portions was less than that found when the residue, sample 9740, was milled. The flour yield of sample 9743, the bin-burned sample, was decidedly low.

The ash content of the flours milled from the stained kernels was higher in each instance than that found in the flour milled from the unstained portion of the original sample.

The acidity of the flour, expressed as lactic acid, was greatest in the flour milled from the badly stained kernels, sample 9742. The flours milled from both the stained-kernel samples made bread that was inferior in loaf volume, shade of crumb, and color of crumb to the loaves baked from the flour milled from the unstained portion of the original sample. A picture of these loaves is shown as Figure 6.

There was a decided earthy odor in all of the samples that increased in intensity with the degree to which the kernel had been stained.

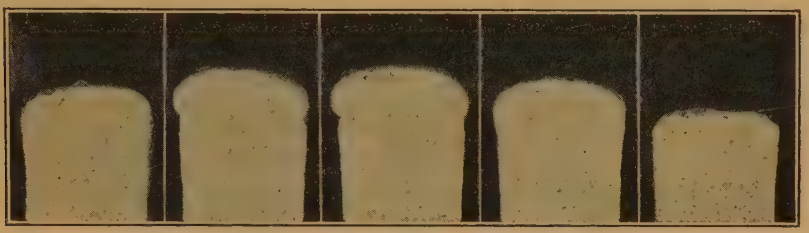

FIG. 6.—Loaves of bread baked from flour milled from header-damaged hard red winter wheat. From left to right, loaves baked from flour milled from samples 9739, 9740, 9741, 9742, and 9743

Separations from two additional hard red winter wheat samples containing kernels of the same types as those described under samples 9207, 9741, and 9742 were studied, and the results were of the same order as the results of the study of the samples mentioned above. The milling and baking quality of wheat kernels which had become discolored because of heating or stained from green weeds had been injured in proportion to the degree to which the kernel was discolored or stained.

STACK-STAINED HARD RED SPRING WHEAT

As final material for study, a sample of stack-stained hard red spring wheat was obtained. This sample was given the number 10008 and was representative of the stack-stained wheat found in the northwestern spring wheat areas. This wheat was cut early, when still green, and was stacked to cure. An examination of the stacks at intervals showed that heating had not taken place to any noticeable extent. On analysis, the sample was found to contain 11.8 per cent of dark green kernels and 8.6 per cent of light green kernels; the remaining kernels were apparently normal in color and appearance.

As in the previous studies, sound, slightly stained, and badly stained kernels were separated from the original sample in quantities

sufficient to make a complete physical, chemical, milling, and baking test of the various types of kernels. The experimental data appears in Table 8.

Sample 10009 represented the unstained portion of the sample and to all appearances was sound in every respect. On account of the difficulty of completely separating all other types of kernels from this type, it contained 2.8 per cent of sample 10010.

TABLE 8.—*Physical characteristics and chemical composition of header-damaged hard red spring wheat, effect of header damage upon yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Physical characteristics of the wheat							Chemical composition of the wheat (basis, 13.5 per cent moisture)						Milling yields		
	Test weight per bushel	Moisture content	Heat-damaged kernels	Kernels damaged by stain	Foreign material	Dark, hard, and vitreous kernels	Commercial grade	Crude protein	Gliadin	Water-soluble nitrogen	Crude fat	Acidity as lactic acid	Ash	Flour	Bran	Shorts
	Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
10008 [2]	59.4	11.8	0	2.0	0	98.2	No. 2 D. N. S.[3]	16.62	10.70	0.479	2.28	0.321	1.63	69.8	16.62	13.50
10009 [4]	59.7	10.6	0	2.8	0	96.7	do.[3]	16.10	10.85	.464	2.34	.319	1.63	68.2	14.06	17.47
10010 [5]	59.4	10.4	0	100.0	0	100.0	do.[3]	16.77	10.84	.501	2.39	.319	1.57	68.1	14.36	16.40
10011 [6]	59.1	10.8	0	100.0	0	100.0	do.[3]	16.99	10.89	.542	2.06	.320	1.60	[7] 64.9	16.20	17.91

Laboratory No.	Water absorption of the flour [1]	Chemical composition of the flour (basis, 13.5 per cent moisture)							Baking data						
		Crude protein	Crude gluten		Gliadin	Ash	Acidity as lactic acid	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor and taste of the hot loaf
			Wet	Dry										
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*C.c.*	*C.c.*	*Score*		*Score*	*Minutes*	
10008 [2]	75.3	16.23	49.32	18.06	13.12	0.446	0.157	2,118	519	88.9	Dark cream gray.	88.0	53	Natural.
10009 [4]	75.6	16.18	48.46	17.85	13.64	.446	.159	2,105	519	89.2	do	86.1	55	Do.
10010 [5]	76.0	16.01	49.71	17.75	13.55	.432	.157	2,003	521	88.2	do	88.0	48	Do.
10011 [6]	76.9	16.33	50.46	18.47	14.58	.425	.107	2,047	523	89.0	Cream gray	86.8	48	Slightly weedy, bitter taste.

[1] Water absorbed plus water originally in the flour.
[2] 10008 is the original sample and contains 79.6 per cent of 10009, 8.6 per cent of 10010, and 11.8 per cent of 10011.
[3] Dark northern spring.
[4] 10009 is the unstained kernels in the sample. It contains 2.8 per cent of 10010.
[5] 10010 is the light green, slightly stained kernels in the original sample. It contains 3.6 per cent of 10009 and 4.9 per cent of 10011.
[6] 10011 is the dark green, badly stained kernels in the original sample. It contains 3.5 per cent of 10010.
[7] Weedy odor on tempering.

Sample 10010 represented slightly stained, light-green kernels. In this sample were 3.6 per cent of sample 10009 and 4.9 per cent of sample 10011. The test weight per bushel seems to be the only outstanding characteristic which can be correlated with the degree to

which the kernel has been stained. Sample 10009, sound kernels, weighed 59.7 pounds per bushel, whereas sample 10011, badly stained kernels weighed 0.6-pound per bushel less. Both samples contained almost the same percentage of moisture and were free from other factors which influence test-weight determinations; consequently the difference in test weight per bushel between the sound and badly stained kernels is significant.

The crude-protein content of the badly stained kernels was greater than that in those samples showing a lesser degree of stain. The percentage of water-soluble nitrogen was also greater in the badly stained kernels.

Less flour was extracted from the kernels that were badly stained than was obtained from the sound wheat in the original sample. Nearly 5 per cent less flour was obtained from sample 10011 than was obtained from sample 10009. When sample 10011 was tempered a decidedly weedy odor was present. This odor carried through into the flour and was noticeable in the hot loaf of bread. The bread baked from the flour milled from sample 10011 also had a decidedly bitter taste.

The crude protein of the flour paralleled the crude protein content of the wheat as the flour milled from the badly stained sample, 10011,

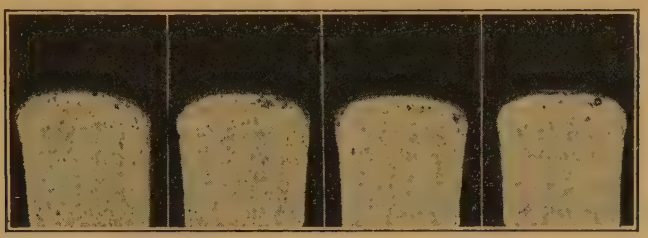

FIG. 7.—Loaves of bread baked from header-damaged hard red spring wheat. From left to right, loaves baked from flour milled from samples 10008, 10009, 10010, and 10011

was higher in protein content than was the flour milled from the apparently sound sample, 10009. The crude-gluten content was likewise higher in the more badly stained kernels.

The ash content of the flours milled from samples 10010 and 10011 was found to be less than that in flour milled from sample 10009.

The titratable acidity of the flour milled from the badly stained sample 10011 was less than that in flour milled from sample 10009. This is in keeping with the finding of Blish [4] that the greater portion of the titratable acidity in immature spring wheat in the bran and shorts.

There was not a great deal of difference in the volume of the loaf of bread baked from flour milled from kernels of the three types. Likewise the texture of the crumb was practically the same for all three loaves of bread. The color of the crumb was slightly inferior in the loaves baked from the flour of sample 10011. A picture of the loaves of bread made from the flour milled from these samples is given in Figure 7.

The fermentation period was approximately 13 per cent shorter in the case of the flours milled from the stained samples 10010 and

[4] BLISH, M. J., EFFECT OF PREMATURE FREEZING ON COMPOSITION OF WHEAT. Jour. Agr. Research 19: 181–188. 1920.

10011. This would indicate a weakness in gluten quality, because from a quantitative standpoint crude protein was present in excess of that in the flour milled from the sound wheat, sample 10009.

The water absorption of the flours milled from wheat kernel of the three types was greatest in flour sample 10011. The water absorption paralleled the crude protein content of the flours.

The odor of the bread was natural except that of the bread made from sample 10011. This gave off a weedy odor in the hot loaf.

As a result of the studies made of the kernels found in this sample, it may be said that only the badly stained, dark-green kernels showed decisively that they were of inferior milling and baking qualities. Beyond a slight reduction in test weight per bushel and in the volume of the baked loaf, the light-green kernels were not outstandingly inferior in milling and baking properties.

From a consideration of the chemical composition of all the stack-stained wheat and the flour milled from it, it is evident that the stained kernels were decidedly immature when cut. The higher percentage of crude protein and the high percentage of water-soluble nitrogen in the stained kernels, as compared with the unstained, is indicative of this condition.

When wheat is cut in an immature condition, some of the kernels are in a more mature condition than others. Naturally when these immature kernels are placed under the anaerobic conditions present in stacked grain a rapid fermentation takes place. The extent to which this fermentation takes place is largely controlled by the supply of easily decomposible carbohydrates, which are always present in immature wheat. Blish [5] has observed in his studies on frost-damaged wheat, that the more immature the wheat the greater is the percentage of crude protein and soluble carbohydrates.

The degree of discoloration or stain may be the resultant of two forces: (1) Heat of fermentation, and (2) absorbed stain due to the presence of a large percentage of weeds that were cut and stacked at the same time that the wheat heads were harvested.

These studies made on the hand-separated portions of all seven samples of header-damaged wheat, indicate the probability that wheat so stained is immature wheat and has a high moisture content which will absorb foreign stain and odor. In badly stack-stained wheat there is usually a reduction in flour yield and an increase in ash in the flour. There is often an accompanying weedy, earthy, or musty odor in the flour and a lowering of most of the properties usually associated with a good loaf of bread.

MILLING AND BAKING STUDIES WITH ADMIXTURES OF BIN-BURNED AND STACK-STAINED WHEAT

ADMIXTURES WITH BIN-BURNED WHEAT

Much damaged and discolored wheat is disposed of by mixing it in certain proportions with sound wheat. Several series of tests were made to obtain evidence regarding the influence of this practice upon the milling and baking value of naturally sound wheat.

A sample of sound hard red winter wheat in good condition in every respect was obtained, and to separate portions of it were added heat-damaged kernels of the two types described under

[5] See footnote 4.

laboratory numbers 8085–B, 9252, and 10018 and under laboratory numbers 8085–C, 9253, and 10019. As prepared, the two series of mixtures contained 0.1, 0.2, 0.5, 1, 3, and 5 per cent of heat-damaged kernels.

The results of these tests are given in Table 9. Under series 1 are given the results obtained by mixing the light tan or skin-burned kernels with sound wheat. In series 2, the admixtures were made with the badly discolored mahogany kernels.

TABLE 9.—*Milling and baking results obtained from samples of heat-damaged wheat mixed with sound wheat, by percentage of heat-damaged wheat used*

Admixture of heat-damaged wheat	Flour		Loaf of bread					
	Yield	Odor	Volume	Color	Texture	Shade of crumb	Heat-damage odor	Heat-damage taste
Series 1—Light-colored, heat-damaged kernels:	*P. ct.*		*C. c.*	*Score*	*Score*	*Color*		
0 per cent	74.3	Natural	2,150	86.5	89.0	Cream gray	Natural	Natural.
0.1 per cent	73.9	do	2,110	86.2	89.5	do	do	Do.
0.2 per cent	74.0	do	2,240	86.3	88.5	do	do	Do.
0.5 per cent	72.6	do	2,270	86.7	88.8	do	do	Do.
1 per cent	73.7	do	2,220	84.8	88.0	Cream	Very slight in hot loaf.	Do.
3 per cent	75.1	do	2,220	84.5	87.8	do	Slight in hot loaf.	Do.
5 per cent	74.3	Slightly heat-damaged.	2,190	81.7	87.0	Dark cream	do	Do.
Series 2—Badly discolored heat-damaged kernels:								
0 per cent	74.5	Natural	2,130	86.5	89.0	Cream gray	Natural	Do.
0.1 per cent	75.7	do	2,140	86.5	89.8	do	do	Do.
0.2 per cent	74.5	do	2,140	88.0	90.0	do	do	Do.
0.5 per cent	73.7	do	2,160	86.8	90.0	do	do	Do.
1 per cent	74.4	do	2,090	81.0	90.0	Dark cream gray.	Slight	Slight bitter taste.
3 per cent	73.0	Slightly heat-damaged.	2,160	74.0	90.3	do	do	Strong bitter taste.
5 per cent	71.9	do	2,100	55.5	89.5	Brown	Strong	Very strong bitter taste.

The results given in Table 9 indicate that the milling quality of sound wheat, in so far as yield and color of flour are concerned, is not appreciably affected by the admixture of 0.1, 0.2, 0.5, or 1 per cent of heat-damaged kernels of either type studied. However, admixtures of 1, 3, or 5 per cent of heat damaged kernels of either type had a decided effect upon the baking quality of such flour as the color and odor of the bread was injured in every instance. Additionally there was a characteristic bitter taste in loaves of bread made from flour which was milled from wheat containing admixtures of 1, 3, and 5 per cent of badly discolored heat damaged kernels.

The degree to which the kernels are heat-damaged determines the extent of the effect upon the quality of the flour and bread. For example, the bread color scores of the 1, 3, and 5 per cent admixture samples of series 1 were 84.8, 84.5, and 81.7 respectively, while the corresponding admixtures of series 2 showed color scores of 81.0, 74.0 and 55.5.

Admixtures containing the most badly discolored kernels in large amounts yielded less flour.

It is again apparent, therefore, that wheat containing only slight amounts of heat-damaged kernels is a milling risk.

ADMIXTURES WITH STACK-STAINED WHEAT

Header-damaged wheat of the type described under laboratory numbers 9207, 9742, 10011, and 10071 was mixed with sound wheat in the proportions given in Table 10. Milling and baking tests and some chemical tests were made on the various admixtures.

The results indicate that badly stack-stained wheat can not be safely mixed with sound wheat in amounts in excess of 5 per cent. Beyond this point, there is a reduction in flour yield, an increase in the ash content of the flour, and a development of poor color and odor in the resulting loaf of bread.

ADMIXTURES OF FLOUR MILLED FROM STACK-STAINED WHEAT

To determine how far flour milled from header-damaged wheat can be blended with sound flour before detrimental results occur, blends were made of sound flour and flour milled from slightly and pronouncedly header-damaged wheat. The blends contained 0.1 0.2, 0.5, 1, 3, 5, and 10 per cent of flour milled from header-damaged wheat. The results of these tests are given in Table 11. This table shows that flour milled from header-damaged wheat of this type can not be successfully blended with sound flour in amounts greater than 0.5 per cent as the dough made from blends of a greater percentage than this has a decidedly bad odor, and if amounts over 1 per cent are used a noticeable flavor is carried through into the bread.

TABLE 10.—*Effect of mixing header-damaged wheat with sound wheat upon physical and chemical composition of wheat, yield and composition of flour, and character of resulting loaf of bread*

Laboratory No.	Description of mixture	Physical characteristics of the wheat								Chemical composition of the wheat,[1] total crude protein	Milling yields		
		Test weight per bushel	Moisture content	Sound kernels	Stain-damaged kernels	Kernels damaged otherwise than by stain	Foreign material	Dark, hard, and vitreous kernels	Commercial grade		Flour	Bran	Shorts
		Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
8460	Sound hard red winter	61.6	10.3	98.7	-----	0.5	0.8	56.8	No. 1 H. W.[2]	11.00	71.2	17.30	11.51
8461	0.1 per cent header-damaged wheat mixed in.	61.6	10.3	98.6	0.1	.5	.8	56.9	do	11.00	71.6	16.69	11.23
8462	0.2 per cent header-damaged wheat mixed in.	61.6	10.3	98.5	.2	.5	.8	57.0	do	11.01	71.7	16.50	11.52
8463	0.5 per cent header-damaged wheat mixed in.	61.5	10.3	98.2	.5	.5	.8	57.3	do	11.03	71.0	16.66	12.22
8464	1 per cent header-damaged wheat mixed in.	61.5	10.3	97.7	1.0	.5	.8	57.8	do	11.06	71.3	16.78	10.62
8465	3 per cent header-damaged wheat mixed in.	61.4	10.3	95.7	3.0	.5	.8	59.8	No. 2 H. W.[2]	11.18	71.2	17.05	11.15
8466	5 per cent header-damaged wheat mixed in.	61.4	10.3	93.7	5.0	.6	.7	61.8	No. 3 H. W.[2]	11.30	70.9	17.54	10.98
8467	7 per cent header-damaged wheat mixed in.	61.2	10.3	91.7	7.0	.6	.7	63.8	No. 4 H. W.[2]	11.43	70.0	17.82	11.73
8468	10 per cent header-damaged wheat mixed in.	61.1	10.3	88.7	10.0	.6	.7	66.8	No. 5 H. W.[2]	11.61	70.3	16.32	12.78
8469	15 per cent header-damaged wheat mixed in.	60.9	10.3	83.7	15.0	.6	.7	71.8	S. G. D. H. W.[3]	11.91	69.6	17.81	12.05
8470	25 per cent header-damaged wheat mixed in.	60.8	10.3	73.7	25.0	.7	.6	81.8	do	12.52	69.5	17.66	11.78
8005	100 per cent header-damaged wheat.	58.2	10.5	0	100.0	.0	.0	100.0	do	17.08	69.2	16.52	13.70

[1] Basis 13.5 per cent moisture. [2] Hard winter. [3] Sample grade dark hard winter.

TABLE 10.—*Effect of mixing header-damaged wheat with sound wheat upon physical and chemical composition of wheat, yield and composition of flour, and character of resulting loaf of bread*—Continued

Laboratory No.	Description of mixture	Chemical composition of the flour[1]		Baking data						
		Total crude protein	Ash	Water absorption of the flour	Volume of the loaf	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time pan to oven	Odor and taste of the hot loaf
		Per cent	*Per cent*	*Per cent*	*C. c.*	*Per cent*		*Score*	*Minutes*	
8460	Sound hard red winter	9.52	0.398	72.7	2,095	91	Cream gray	90	60	Natural.
8461	0.1 per cent header-damaged wheat mixed in.	9.58	.418	72.4	2,115	91	do	90	63	Do.
8462	0.2 per cent header-damaged wheat mixed in.	9.52	.415	72.3	2,130	91	do	90	62	Do.
8463	0.5 per cent header-damaged wheat mixed in.	9.58	.407	73.6	2,175	91	do	90	63	Do.
8464	1 per cent header-damaged wheat mixed in.	9.58	.422	73.2	2,095	91	do	89	64	Do.
8465	3 per cent header-damaged wheat mixed in.	9.52	.403	72.6	2,155	90	do	90	65	Do.
8466	5 per cent header-damaged wheat mixed in.	9.80	.417	73.3	2,135	91	do	91	62	Do.
8467	7 per cent header-damaged wheat mixed in.	9.80	.425	72.7	2,175	91	do	91	63	Slightly off flavor.
8468	10 per cent header-damaged wheat mixed in.	9.92	.427	72.1	2,165	91	do	92	62	Do.
8469	15 per cent header-damaged wheat mixed in.	9.80	.456	71.6	2,120	92	Dark cream	92	57	Poor flavor. Slight odor in dough and loaf.
8470	25 per cent header-damaged wheat mixed in.	10.26	.491	70.9	2,130	91	do	91	56	Pronounced odor and bad flavor.
8005	100 per cent header-damaged wheat.	13.57	.605	76.3	2,050	89	Cream gray	89	44	Musty and earthy.

[1] Basis 13.5 per cent moisture.

TABLE 11.—*Effect upon character of resulting loaf of bread of flour blends made by mixing varying amounts of flour milled from header-damaged with sound flour*

Laboratory No.	Flour blend	Water absorption	Volume of loaf	Color of bread	Texture of crumb	Color of crumb	Fermentation time, pan to oven	Odor and taste
	Per cent	*Per cent*	*C. c.*	*Score*	*Per cent*		*Minutes*	
Series 1:								
10110	0.0	60.0	2,055	90.0	90.5	Cream gray	55	Natural.
10111	.1	59.7	1,985	89.0	90.5	do	55	Do.
10112	.2	60.0	2,040	91.0	91.2	do	57	Do.
10113	.5	60.0	2,020	88.7	90.0	do	55	Do.
10114	1.0	60.3	2,020	89.0	90.4	do	58	Odor in dough, but not in bread.
10115	3.0	60.3	2,070	89.0	89.2	do	59	Odor and taste in hot loaf.
10116	5.0	60.0	2,020	89.0	90.7	do	56	Odor and taste in hot and cold loaf.
10117	10.0	60.0	2,080	89.0	91.0	Dark cream gray.	60	Pronounced musty odor and flavor.
9522	100.0	63.2	2,045	87.5	89.1	Very dark cream gray.	48	Musty odor and taste in dough and hot loaf.
Series 2:								
10118	0.0	60.0	2,025	89.5	89.1	Cream gray	60	Natural.
10119	.1	60.0	2,020	88.5	90.5	Cream	52	Do.
10120	.2	60.0	2,000	88.2	90.6	Cream gray	57	Do.
10121	.5	60.3	2,005	89.5	90.2	do	58	Do.
10122	1.0	60.3	2,080	87.5	90.2	do	61	Odor in dough, but not in bread.
10123	3.0	60.1	2,090	90.5	91.2	do	60	Slight taste in bread.
10124	5.0	60.3	2,115	89.9	91.7	Dark cream gray.	59	Slight odor and taste.
10125	10.0	60.6	2,110	91.5	91.0	do	55	Pronounced odor and taste.
9521	100.0	67.7	2,080	73.2	83.5	Dark gray	53	Rancid and musty.

KEEPING QUALITIES OF FLOUR MILLED FROM HEADER-DAMAGED WHEAT

It has been stated frequently that flour milled from header-damaged wheat will not keep in storage. It is argued that whereas flour milled from such wheat may not show evidence of injury immediately after milling, if it is placed in storage for a short period inferior qualities will develop. Information on this subject was sought by milling 100 pounds of flour from two samples of header-damaged wheat and comparing its keeping qualities, as judged from the baking tests at intervals of two months, with flour milled from sound wheat. The results of the comparative study are given in Table 12. They show that the flour milled from the header-damaged wheat samples 9521 and 9522 deteriorated in storage to a marked extent. With but one instance the volume of the loaf of bread, the texture of the crumb, the shade of the crumb, and the color of the loaf of bread were injured as the period of storage increased.

On the other hand, the keeping qualities of sample 9523, the check or sound sample, seemed to improve somewhat as the length of storage time increased.

TABLE 12.—*Comparison of keeping quality of flour milled from header-damaged and from sound wheat*

Date of baking	Water absorption of the flour	Volume of the loaf	Texture of the crumb	Shade of the crumb	Color of the bread	Fermentation time, pan to oven	Odor and taste in the dough and in the baked loaf
1923							
Sample 9521:	*Per cent*	*C. c.*	*Score*		*Score*	*Minutes*	
Mar. 3	68.0	2,330	90	Cream gray	92	56	Slightly musty.
May 3	67.0	2,325	89	do	89	52	Bad odor in dough and loaf. Bad taste; rancid.
July 26	67.7	2,080	83	Dark gray	73	53	Worse condition than at last baking.
Sample 9522:							
Mar. 3	63.0	2,170	93	Cream gray	91	53	Very musty.
May 3	64.0	2,190	91	do	90	49	Musty taste in bread; musty odor in dough.
July 26	63.2	2,045	89	Dark cream gray.	87	48	Musty odor and taste in dough and hot loaf; more pronounced than at last baking.
Sample 9523:							
Mar. 3	58.8	1,955	91	Cream	91	55	Natural
May 3	61.2	2,015	90	do	89	55	Do.
July 26	60.2	2,065	90	do	89	55	Do.

HEAT-DAMAGE-RESISTING QUALITIES OF WHEAT OF DIFFERENT CLASSES

The question has been raised whether certain classes of wheat will ferment or heat more readily than others when exposed to the same conditions.

Information was obtained on this phase of the problem by subjecting wheat samples representing the five commercial classes, at the same time and for the same length of time, to the same conditions of moisture and temperature. Each sample was moistened so that it contained, at the beginning of the test, 16.5 per cent of moisture. A bushel of each class of wheat was placed in a separate tin container

which was later sealed with paraffin. The containers and contents were placed in a temperature-controlled incubator and kept at a temperature ranging between 105° and 107° F. for three weeks. At the end of that time the containers were removed and the contents of each can were tested for the factors of quality shown in Table 13. These results were compared with results from a similar series of tests made upon portions of the wheats not subjected to treatment. In all, three samples of hard red winter wheat, and one sample each of hard red spring wheat, soft red winter wheat, durum wheat, and common white wheat were studied.

As a result of the treatment, heat-damaged kernels developed in each of the samples under test in amounts varying from 0.3 to 4.5 per cent. The degree to which the kernels were heat damaged does not seem to be associated with the class of wheat, as one of the samples of hard red winter wheat and the sample of soft red winter wheat developed practically the same quantity of heat-damaged kernels.

On the other hand, as would naturally be expected, there was a difference in the resistance that individual samples within the same class of wheat exhibited to the development of heat-damaged kernels. Thus, under the same conditions, the three samples of hard red winter wheat contained 0.5, 1.4, and 4.5 per cent of heat-damaged kernels, yet of these three samples the one containing the greatest percentage of heat-damaged kernels made the best loaf of bread.

As before, the heat-damaging process affected the test weight per bushel, the commercial grade, the milling yields, and the ash content of the flour, and in every instance flour milled from these heat-damaged wheats produced a very inferior loaf of bread.

LABORATORY TESTS FOR HEAT-DAMAGED WHEAT

The present method of determining heat damage in wheat is not scientifically exact because in determinations by the eye the definitions employed are subject to varying interpretations. Therefore, search has been continuous for a simple laboratory test to overcome these variations.

The only test of prominence that has any merit is the Bamihl [6] test, which makes use of the fact that during the fermentation process the gluten is affected and fails to agglutinate. This fact is used as an index of the heat-damaged condition of individual kernels. The test works fairly well on samples that show a fair degree of discoloration, but its value is questionable on samples of line character, like skin-burned kernels, which are so often the subject of discussion.

HOW TO AVOID HEAT DAMAGE TO WHEAT

Much of the wheat damage in recent years is chargeable directly to one or more of the careless ways the crop is handled in many localities. The practices responsible for much of this damage are poor shocking, stacking green or wet wheat, threshing when the wheat is too green or too wet, and providing unsuitable storage for the threshed grain.

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[6] FRANK, W. L. CHEMICAL TEST FOR HEAT-DAMAGED WHEAT. Grain Dealers Jour. 48: 321. 1922.

TABLE 13.—*Resistance to heat-damage conditions displayed by wheat of different classes; effect of heat damage upon physical characteristics and chemical composition of wheat, upon yield and composition of flour, and character of resulting loaf of bread*

Class of wheat	Laboratory number	Physical characteristics of the wheat							Chemical composition of the wheat,[1] total crude protein	Milling yields		
		Test weight per bushel	Sound kernels	Heat-damaged kernels	Kernels damaged otherwise than by heat	Foreign material	Dark, hard, and vitreous kernels	Commercial grade		Flour	Bran	Shorts
		Lbs.	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Hard red winter, check	85	58	98.7	0	1.2	0.1	68.4	No. 4 H. W.[2]	13.13	70.03	15.01	14.46
Hard red winter, treated	86	52.3	94.3	4.5	1.1	.1	27.3	S. G. H. W.[3]	13.13	69.51	15.31	13.21
Hard red winter, check	87	61.1	98.7	0	.5	.8	96.8	No. 1 H. W.[2]	11.00	69.12	13.90	14.89
Hard red winter, treated	88	56.7	96.7	1.4	.7	1.2	7.6	No. 5 Y. H. W.[4]	11.00	54.84	14.09	14.47
Hard red winter, check	91	59.5	98.3	0	.5	1.2	32.8	No. 2 H. W.[2]	10.33	69.75	15.95	12.27
Hard red winter, treated	92	54.4	97.8	.5	.5	1.2	4.6	No. 5 Y. H. W.[4]	10.33	71.94	13.96	12.44
Hard red spring, check	89	61.7	98.6	0	1.4	Trace.	19.0	No. 1 R. S.[1]	10.60	72.69	13.17	13.96
Hard red spring, treated	90	56.3	97.8	.9	1.3	Trace.	20.0	No. 5 R. S.[5]	10.60	69.87	12.34	16.25
Soft red winter, check	93	60.2	99.3	0	.7	0	----	No. 1 R. W.[6]	11.17	68.52	16.00	14.87
Soft red winter, treated	94	54.2	94.7	4.4	.9	0	----	S. G. R. W.[7]	11.17	68.74	14.52	13.72
Durum, check	95	61.9	96.3	0	1.2	2.5	67.2	No. 3 Durum	11.25	66.74	14.73	18.84
Durum, treated	96	56.0	94.7	1.0	2.6	1.7	34.7	No. 5 Durum	11.25	63.93	13.47	21.76
Common white, check	97	61.5	99.8	0	.2	Trace.	----	No. 1 W. W.[8]	11.07	65.39	18.32	15.40
Common white, treated	98	54.6	94.9	.3	4.8	Trace.	----	No. 5 W. W.[8]	11.07	62.25	17.22	14.22

Class of wheat	Chemical composition of the flour[1]		Baking data								
	Total crude protein	Ash	Water absorption of the flour	Loaf volume	Volume per 100 grams of dry matter	Texture of the crumb	Shade of the crumb	Color of the crumb	Fermentation time, pan to oven	Odor and taste of the hot loaf
	Per cent	*Per cent*	*Per cent*	*C. c.*	*C. c.*	*Score*		*Score*	*Minutes*	
Hard red winter, check	11.43	0.526	68.9	2,030	503	92	Cream gray	92	49	Slightly musty.
Hard red winter, treated	11.92	.710	66.9	1,465	487	93	Light brown	95	44	Very musty.
Hard red winter, check	9.57	.459	73.0	2,045	520	91	Cream	90	55	Natural.
Hard red winter, treated	9.75	.608	66.2	1,230	489	50	Cream brown	60	46	Rancid.
Hard red winter, check	9.20	.441	71.4	2,030	512	89	Cream	90	71	Natural.
Hard red winter, treated	9.28	.626	65.8	1,210	493	15	Dark cream	33	30	Rancid.
Hard red spring, check	9.39	.553	71.8	1,970	520	83	Cream gray	88	70	Natural.
Hard red spring, treated	9.42	.780	66.4	1,120	490	20	Brown	51	43	Rancid.
Soft red winter, check	9.99	.439	72.6	2,170	515	94	Light cream	95	63	Natural.
Soft red winter, treated	10.18	.620	67.6	1,690	484	79	Dark cream	52	57	Musty.
Durum, check	10.55	.752	76.1	1,990	513	93	Cream	89	49	Natural.
Durum, treated	10.40	.872	68.8	1,180	499	30	Cream brown	45	32	Rancid.
Common white, check	9.24	.425	70.3	2,005	498	92	Light cream	93	50	Natural.
Common white, treated	9.44	.773	66.3	1,210	470	15	Light brown	40	28	Rancid.

[1] Basis, 13.5 per cent moisture.
[2] Hard winter.
[3] Sample grade hard winter.
[4] Yellow hard winter.
[5] Red spring.
[6] Red winter.
[7] Sample grade red winter.
[8] Western white.

The practical way to avoid damage in wheat is to make use of the best-known methods of handling the crop. It pays better in the long run than taking chances by employing the inadequate or careless methods so often used. Many farmers know that they are taking a risk when the shocks are badly made or when threshing is done when the grain is wet, but they feel they are helpless and can not do otherwise. They charge the conditions to incompetent harvest labor and to the fact that when the threshing crew comes around they are compelled to take their turn or delay threshing indefinitely. These conditions unquestionably could be remedied by concerted community action. If the wheat growers in any given locality were to unite in a demand for better work, much of this difficulty could be avoided.

Other farmers voluntarily take the increased risk involved in the inadequate methods of handling the crop and depend on favorable weather to keep them from suffering loss. The claim is made that this system reduces the expense of production. This no doubt is true in favorable seasons, but the loss likely to occur from its practice in unfavorable seasons may more than offset the savings made in the few good seasons. A loss of 5 to 10 or more cents per bushel on damaged wheat caused by faulty methods of handling the crop would usually pay for the extra time and labor required to protect the crop from such damage.

There are two good methods of handling the wheat crop which are practical and adaptable to the conditions common to any given locality. The methods of harvesting now used to a great extent in the hard red winter wheat areas make use of the binder, which cuts and binds the crop into bundles, and the header, which cuts the crop just a few inches below the heads and then elevates the heads into a wagon barge or a small thresher which is hauled alongside. The combine, which is a header and thresher combined into one machine, is now in rather general use in certain localities. Each method has advantages and disadvantages under varied conditions. The binder is the older and the combine the newer of the machines.

The binder has an advantage over the other methods because with it wheat may be cut, bound, and shocked with safety before it is as ripe as demanded by the other methods. The straw from bound wheat is kept in a better condition for use later as feed or for other purposes.

Early harvesting reduces the risk of damage to the standing wheat from storms by shortening the time it is left standing in the field. The bundles should be set in well-built shocks of about 12 bundles each and left to cure sufficiently to be threshed or stacked. The time required for this curing depends somewhat upon the condition of the wheat and the weather. Usually a week or 10 days is long enough. If the shocks are well made, light rains will not damage the grain, and the damage from heavy rains will be much less than when the shocks are poorly made.

Threshing should be delayed until the grain is well seasoned. Then there will be no danger under normal conditions that the threshed grain will spoil while it is in storage. This system of handling the wheat crop is adapted to humid areas where winter wheat is produced.

Threshing from the shock saves the time and expense required to stack the bundles, but the risk of damage to the grain from unfavorable weather is often increased if threshing is delayed until the

grain is cured sufficiently for safe storage. Early threshing from the shock increases the risk that the grain will spoil in storage unless special precaution is taken to provide suitable storage.

The header may be used advantageously in sections where the wheat is too short to bind into bundles and where rather dry weather is usual during the harvest period. Headed wheat usually is stacked and left to cure before it is threshed, but in recent years some threshing has been done direct from the header. This is accomplished either by hauling the wheat in barges to a stationary threshing machine set at some convenient place in the harvest field, or by hauling a small thresher alongside the header so that the grain is fed direct from the header into the thresher. These methods of handling the crop reduce the cost of production by saving the time and labor required to stack the headed grain, but the risk that the threshed grain will be damaged in storage is increased. It is dangerous to put such grain into ordinary storage and leave it more than a few days without thorough ventilation. Otherwise there is much danger that it will heat.

The use of the combine is growing in favor among the wheat producers in Kansas, Oklahoma, and certain other States because it materially reduces the cost of harvesting and threshing the crop. It saves time and labor, the straw is left distributed on the field, and the land can be plowed immediately after harvest. Early plowing is recognized by many farmers as a factor favorable to higher yields in the next crop. The chief drawback to the use of the combine in the Middle Western States is the question of storage for the threshed grain. Often such grain is not in a safe storage condition. Many farmers realize this fact and will not take the risk but sell direct from the combine, although they may have to take a discount. They claim that with a discount of several cents per bushel they are still ahead of results obtained from the old methods of harvesting and threshing. The markets readily absorb a limited quantity of this kind of wheat, but they may not be able to handle all that may be offered if the use of the combine continues to increase. In that event suitable farm storage will become essential.

Combine-harvested wheat usually will keep in storage if harvesting is delayed until the wheat is ripe and dry. Most experienced combine operators do not attempt to harvest wheat when it is not in condition for threshing and storage.

Suitable storage for the threshed grain or the use of a practical method to dry it so that it can be stored safely seems to be essential to success in early threshing either from the shocks or with the combine. It is an established fact that grain that is damp or tough as a result of too early threshing or from recent rains is almost sure to become musty or heat-damaged if left very long in ordinary farm storage or elevators without being stirred, ventilated, or artificially dried. Many farmers and elevator operators have learned that fact by disastrous experiences during the last few years.

New wheat and wheat tough from recent rains may be conditioned so it will keep in storage by drying it in commercial driers, which are built at terminal elevators for that purpose, or by running it from one bin to another so the air can pass through the stream of wheat and dry and cool it. Because of the expensive equipment, the former method is practical only at terminal elevators where large quantities

of wheat are handled, and the latter method can be used with satisfaction only at storage places equipped with mechanical means of handling the grain.

A practical method of curing this grain on the farm so it can be stored with safety and held until the market is ready for it is highly desirable; otherwise the farmer is likely to lose in discounts by forced early sale all or more than he has saved in time and labor over the old way of handling the crop.

Apparently success in storing new wheat that is damp or wet is attained only by keeping it cool and well ventilated. Results from preliminary investigations indicate that this can be done by equipping the bins with ventilators which furnish thorough ventilation to the grain by carrying off the excess moisture and supplying fresh air from outside. It has not been definitely determined how much ventilation is required to give satisfactory results. If wheat is exceptionally green and soft, or wet from rains, it no doubt requires much more ventilation than wheat that is just a little tough.

The temperature of the wheat at the time it is stored is a factor to be considered. When threshing is done on a hot day and the grain is run into a wagon box and allowed to stand exposed to the direct rays of the sun for several hours it absorbs considerable sun heat. In such cases the temperature of the wheat is much higher than that of the surrounding atmosphere. If this wheat is stored without being cooled to the atmospheric temperature it is likely to heat because its high temperature is favorable to fermentation.

VENTILATING FARM GRANARIES

Ventilators for grain may be constructed of wood or perforated metal. For ventilating farm granaries, ventilators made of wood are satisfactory and are more economical in construction than those made of metal. The material is less expensive, and they can be made on the farm during spare time. There are several satisfactory ways to construct wooden ventilators. The main point is to provide an air space through the mass of grain, which can carry off the moisture-laden air and replace it with dry fresh air from outside the bin.

One way to construct a ventilator is to use two boards 6 inches wide for the sides and nail 1 by 2 inch cleats, 12 inches apart, from center to center across the top and bottom. The cleats should be 8 inches long and mortised in so they will come flush with the edges of the boards. The top and bottom should be covered with screen 16-mesh wire (fig. 8).

The position the ventilators should occupy in the bin and the number needed depend upon the construction of the bin to be ventilated and the dampness of the stored grain. The ventilators must draw enough fresh dry air from outside the bin, through the mass of grain, to absorb the excess moisture from the damp grain. The ends of the ventilators must fit into or be flush against holes cut into the outer walls of the bins. For moderately tough wheat, stored in small-to-average farm bins, ventilators spaced 2 to 3 feet apart are usually satisfactory.

It is a question whether this method of ventilation is sufficient or practical for storing grain that is really wet, and it is of doubtful value for very large bins. Wet grain should be dried in some commercial drier before it is put into storage.

SUMMARY

Because of faulty methods of handling a large portion of the wheat crop, a considerable quantity of wheat arrives each year at the markets in a heated and damaged condition.

Wheat of this type is outwardly characterized by a discoloration of the kernel. According to the severity of the fermentation or

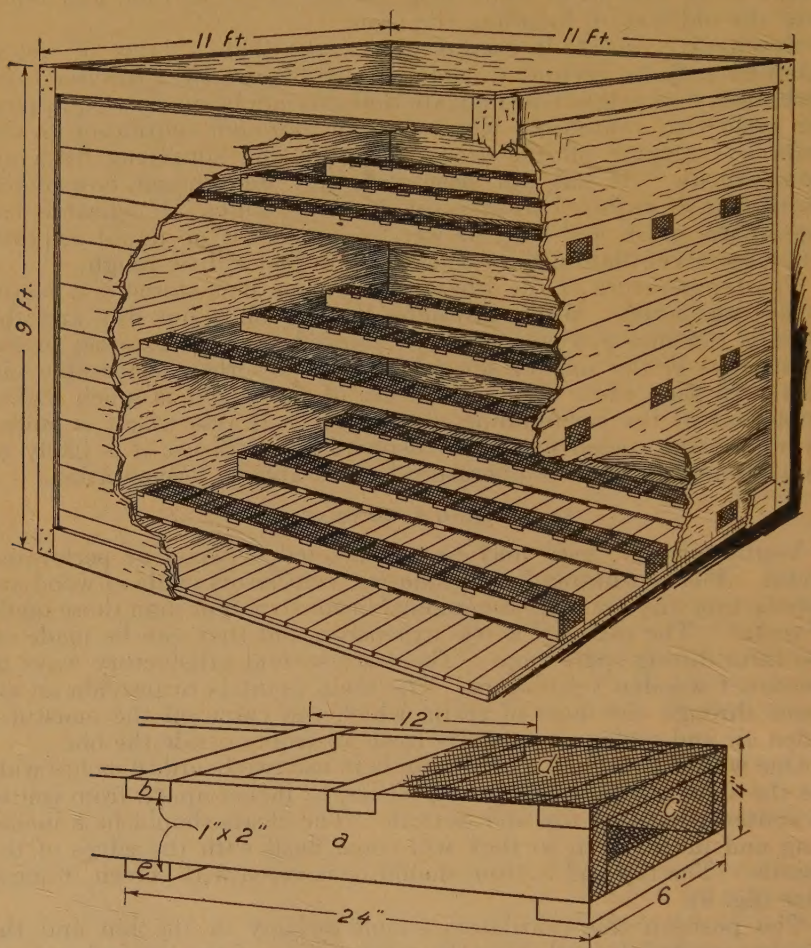

FIG. 8.—Ventilated wheat bin. Upper figure: View of ventilators in position in the bin. These are placed 3 feet apart in tiers. The tiers are also 3 feet apart, one above the other, with openings in the sides of the bin. Lower figure: Detail drawing of structure and dimensions of ventilator: *a*, Side of ventilator; *b*, cleat mortised in upper edge of *a*; *c*, *d*, wire screen over end and top of ventilator; *e*, cleat nailed on bottom to hold the ventilator together and to raise it from floor

heating process to which the kernels have been exposed, the kernels change from their natural color, passing from light yellow or amber through the various shades of dark yellow and brown to a deep brown or red mahogany color in the most extreme condition of heat damage.

Physical, chemical, milling, and baking tests were made of samples of wheat discolored by the heat of fermentation, and the results obtained from these tests were compared with similar data secured from a study of sound wheat.

The tests of the heat-damaged bin-burned wheat were carried forward in two sections. In the first section the discolored kernels were separated by hand from a bulk sample of known origin, on which were made the various tests described. Later tests were made to note the effect on the milling and baking properties of mixing certain percentages of heat-damaged wheat of different types with the sound wheat.

The results obtained indicate that wheat discolored to the shade popularly known as skin-burned is of inferior milling quality. This is particularly true if this type of wheat is found in the country shipments before they have been mixed at an elevator as less than 0.5 per cent of skin-burned kernels in country-run wheat is fair evidence that the milling and baking quality of the whole lot is distinctly injured. Other tests made on this country-run wheat show that the so-called sound wheat in which the heat-damaged kernels were found is not really sound but is in a "sick" or weakened condition. Some indication of how badly the sound wheat has been injured can be had by noting the character and quantity of the heat-damaged kernels present in a sample.

In the tests described, 1 per cent of slightly skin-burned wheat, or 0.5 per cent of badly heat-damaged kernels, when mixed with sound wheat, injured the milling and baking qualities of the sound wheat.

Stack-stained or header-damaged wheat is a distinctly different type of heat-damaged wheat. The presence of stack-stained kernels is occasioned by the cutting and stacking of immature wheat that is moist. Stack-stained wheat is in reality immature wheat which has been discolored by the heat of fermentation while in the stack. This discoloration is often aided by the presence of large quantities of moist green weeds mixed with the stacked grain.

Wheat that is badly stack-stained is of inferior milling quality, inasmuch as it usually gives a low yield of flour and the flour has a high ash content. The bread made of such flour has poor color, a bitter taste, and an undesirable weedy odor. The more severely discolored the kernels, the more inferior is the resulting flour and bread.

Stack-stained wheat, although at times as badly discolored as bin-burned wheat, is not as seriously injured as bin-burned wheat of the same color.

Stack-stained wheat does not carry well in storage under slightly abnormal conditions, nor does the flour milled from it store well.

The condition of the grain at the time it is stacked or stored in bins is more responsible for heat-damaged kernels than are the methods of harvesting or threshing. Early harvesting reduces the risk of damage to the standing wheat, but threshing should be delayed until the grain is well-seasoned. When the combine is used the wheat should not be cut until it is in condition for threshing and storing.

Apparently success in storing new wheat that is damp or wet depends upon keeping it cool and well ventilated. Results from preliminary investigations indicate that this can be done by equipping the bins with ventilators which furnish thorough ventilation to the grain by supplying fresh air from outside which carries off the excess moisture. It has not been determined definitely how much ventilation is required to give satisfactory results. If the wheat is exceptionally green and soft, or wet from rains, it probably requires much more ventilation than wheat that is just a little tough.

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